

2013 International Workshop on EUV and Soft X-Ray Sources

Dublin, Ireland
November 3-7, 2013

Workshop Summary

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Notes taken during the meeting – Please point out any mistakes!

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Workshop Agenda

Tuesday, November 5, 2013

- **8:40 AM Session 2: Keynote Session -1**
- **EUV Lithography: Current and Future Requirements and Options? (S2)** Vadim Banine, *ASML/Cymer*
- **Reminded that EUVL is a cost effective solution compared to SADP/SAQP and enables 50% scaling for the 10 nm logic node**
- Relationship between TPT and Source Power (125 WPH-250 W)
- 13 nm HP L/S and 17 nm HP CH
- **35 kW CO₂ laser (pulse mode is at 30% of CW), Maximum 5.5% CE predicted, max 5% measured**
- **3.7% CE, 720 at source, 176 W at IF estimated**
- **32 hours run for 40 W and 50 W. 50 W with good dose control demonstrated**
- **Cap layer development has increased lifetime to > 6 months. In -situ cleaning using RF plasma**
- List of challenging questions to workshop participants!
- 6.8 nm option is now in pre-competitive arena

Workshop Agenda

Tuesday, November 5, 2013

- **8:40 AM Session 2: Keynote Session -1**
- **Enabling EUVL for HVM Insertion (S3)** Mark Phillips, *Intel*
- **Source power roadmap has lost credibility.** 2 year lead time for tool. At risk that power levels will be ready for HVM
- 40 W, 0.5% stability is in lab and not in field – need it for 3300 scanner
- **Source for NXE 3300B has 60 W in open loop. Need 40-80 W stable power in field for 2017 HVM insertion. Looks feasible.**
- For insertion progress needs to happen on all fronts: resists, tool, reticle
 - OK - scanner hardware, resolution
 - Challenge: resist outgas testing is slowing down development
 - Serious issues – LWR – (non CAR resists need large dose) – triangle of death and sorrow! Reticle defects and source power. Missing in-situ inspection and AIMS tool (will be seriously limited due to source)
 - Need EUV pellicle (Jim Wiley IEUVI Mask TWG, October 2013)- poly silicon films
 - **Pellicles mean that e-beam inspection for defects will not work and we need actinic inspection**
 - **Metrology source brightness – 10 (today), need (30), want 100 (W/mm²sr). Need to be designed together with tools and suppliers to fund source development.**
- **Milestones: For insertion – 100 W stable by Q4 2014, 200 W demo, 250 W by H1 2015**
- Need new work for 1000 W sources. Alternative technologies for drive lasers and sources that are needed by 2019?

Workshop Agenda

Tuesday, November 5, 2013

- **10:40 AM Session 3: HVM EUV Sources**
- **Update of High CE, High Power HVM LPP-EUV Source Development (S21) (Invited)** Hakaru Mizoguchi, *Gigaphoton*
- Dual wavelength prepulse, perfect ionization for magnetic field mitigation
- 7- hours stable operation of droplet delivery
- **Picosecond prepulse improves CE and reduces mists**
- Transvers flow CO2 laser development with Mitsubishi and axial flow development with Trumpf
- **Collector with IR rejection with Rigaku – much better than present IR filter with only 10% loss**
- Propose 25 kW CO2 laser, 4% CE, 100 K Hz, 250 W EUV source power
- **15 W, 100 KHZ, 50% duty cycle, 1.5 % CE has been improved to 2.5%**

Workshop Agenda

Tuesday, November 5, 2013

- **10:40 AM Session 3: HVM EUV Sources**
- **BEUV Nanolithography: 6.7 or 11 nm? (S19).** N. I. Chkhalo, *Institute for physics, Russia*
- Theoretically productivity at 6.7 nm is higher than 13.5nm
- La/B₄C/C R = 58.6%. Magnetron sputtering and ion beam polishing
- BEUVL at 6.7 nm is very challenging so we need to look at alternate wavelength
- **BEUV around 11 nm – R = 8.6% for 10 mirror system (2 x improvement, 4.4 % for 13.5 nm)**
 - *Need to measure CE of Xe at 11.2 nm*
- **Cost and benefit analysis for this switch?**

Workshop Agenda

Tuesday, November 5, 2013

- **Session 3: HVM EUV Sources**
- **Development of Thin Disc Laser in HiLASE Project (S24)** Taisuke Miura, *HiLASE Project, Czech Republic*
- High average power pulsed laser development – important for pre-pulse application
- Laser 1: 50 W, 100 K Hz, 0.5 mJ, 1 ps pulse
- Laser 2: 45 W, 45 mJ, 1 K Hz, 1 ps pulse

Workshop Agenda

Tuesday, November 5, 2013

- **Session 3: HVM EUV Sources**
- **Research Review on Plasma-based EUV Sources at RnD-ISAN/EUV Labs (S40)** V. M. Krivtsun, *RnD-ISAN /EUV Labs*
- **Power scaling via increase of pulse energy (pulse length) or pulse frequency**
- CO2 laser TEA – 4 μ s, EBP: 60 μ s
- **Closed tin system with tin jets of velocity of 5-15 m/s (max temperature of 350 C)**
- **CO2 Lasers**
 - CE >3% at 2.5 J, 400 micron laser spot, 1.8 GW/cm² of laser power
 - Longer pulse are available from 10-80 J, 10-60 μ s EBSD laser - < 1% CE observed
- **Need to tackle absorption of Sn absorption after every pulse. How well this approach can be scaled?**
- Nd Lasers
 - 2% CE, 1.5 ns, 300 mJ, 30-50 μ m spot size
- In BEUV region, 1.8% CE in 0.04 nm band for Gd demonstrated

Workshop Agenda

Tuesday, November 5, 2013

- **Session 3: HVM EUV Sources**
- **A Systematic Study of Colliding Plasmas for EUVL (S25)**
- Emma Sokell, *University College Dublin*
- Colliding plasma can create a stagnation layer
- Nd: YAG colliding plasma with CO₂ laser (50 ns) reheat
- CE of 1.4% with flat target, 2.1 % with Wedge target
- **13.2 mJ in-band is CE of 4.9% of CO2 laser! Approach can be applied to HVM sources but have not been tried yet.**

Workshop Agenda

Tuesday, November 5, 2013

- **1:20 PM Session 4: Modeling**
- **Development of Radiation Hydrodynamic code STAR for EUV Plasmas (S15)**
- *Atsushi Sunahara, Institute for Laser Technology, Japan*
- EUV conversion efficiency = laser absorption x X-ray conversion x EUV spectral efficiency
- CO₂ laser 10E10 W/cm², 11 ns, 200 micron dia, density scale length keeps 25 micron in time due to lateral flow from the laser spot
- **Liquid vapor region is very important for the dynamics of the tin droplet irradiated by the pre-pulse**
- **8% CE is possible for longer time lengths**

- **Modeling of the Laser Plasma Interaction for the Development of Efficient EUV Sources (S17)**
- *Akira Sasaki, Japan Atomic Energy Agency*
- Estimation of conversion efficiency
- Development of hydrodynamics code to model phase transition

Workshop Agenda

Tuesday, November 5, 2013

- **1:20 PM Session 4: Modeling**
- **Observations of EUV Spectra from Highly Charged Heavy Ions in Optically Thin Plasmas for Benchmarking of Models (S16)**
- Chihiro Suzuki, NIFS, Japan
- Highly charged ions can be observed in optically thin plasmas – LHD
- **Difference in the spectra between LHD and EUV Sources - The UTAs from 4f are missing**
- Observed dependance of EUV spectrum on Z

Workshop Agenda

Tuesday, November 5, 2013

- **1:20 PM Session 4: Modeling**
- **Fundamental Atomic Process in Source Development for Beyond EUV Lithography and “Water Window” Imaging (S38)**
- Padraig Dunne, *University College Dublin*
- **Power density required 80-130 eV for Gd plasma at 6.x nm**
- Optimum temperature, Gd- 110 eV, Tb – 120 eV
- Peak wavelength shifts with Te and peak of Gd/Tb do not coincide with peaks of ML
- **Role of dielectric combination**
- **What about Ga/Ge for 6.x nm?**
- **What about mixed targets of Gd and Tb for 6.x ?**
- **Zr and Bi as choice for source material for water window**

Workshop Agenda

Tuesday, November 5, 2013

- **1:20 PM Session 4: Modeling**
- **Advances in Modeling of Physical Processes in Plasma-based Sources of EUV Radiation (S39)**
- V.V. Ivanov, *RnD-ISAN*
- **Model assists in the determination of source operation region with low collector contamination rate**
- Sn droplet can be transformed into disk shaped targets

Workshop Agenda

Tuesday, November 5, 2013

- **1:20 PM Session 4: Modeling**
- **Pulsed-power Based Bright EUV Light Source for Metrology (S48)**
- **S. Zakharov, NAEXTSTREAM, France**
- Zenith – multi physics model -3D model
- 1.6% CE for Xe Capillary discharge source from EPPRA
- Proposal of sources for Mask inspection
- Plasma lens- wave-guiding refractive structure
- **New source data by SPIE AL 2014**

Workshop Agenda

Tuesday, November 5, 2013

- **3:35 PM Session 5: Optics**
- **Collector Development with IR Suppression and EUVL Optics Refurbishment at RIT (S30) (Invited)**
- Yuriy Platonov, *Rigaku Innovative Technologies*
- **Turned grating on optical surface to diffract 10.6 microns**
- **125 x IR suppression on Demo Collector**
- **51% average reflectivity for unpolarized light**
- Illumination optics refurbishment:
 - 1.2 % reflectivity loss after 5 refurbishment cycles
 - Ion beam etching causes large reflectivity loss 6-12 %

Workshop Agenda

Tuesday, November 5, 2013

- **3:35 PM Session 5: Optics**
- **EUV Optical Elements with Enhanced Spectral Selectivity for IR Radiation (S31) (Invited)**
- V. V. Medvedev, *FOM Institute DIFFER*
- Scattered IR radiation in 6.x nm radiation sources
- La/B and La/B₄C are opaque to IR so need different material for anti-reflection based technique
- LaN/B $n = 3.3 + 0.3i$ for 10.6 micron
- **50% IR rejection achieved, with 25% EUV reflection at 6.7 nm**
- **Proposal to combine grating and anti-reflection approach which may be needed for GP's two wavelength approach**

Workshop Agenda

Tuesday, November 5, 2013

- **3:35 PM Session 5: Optics**
- **Design of Freestanding Film Elements for HVM tools of EUV Nanolithography (S28) (Invited)**
- Alexey Lopatin, *Institute for Physics, Russia*
- Up to six materials can be combined in the ML structure
- 30-100 mm with thickness of 100-200 nm with $T = 40-50\%$ at 13.5 nm
- Zr SPF, 50 nm, 76% transmission
- (Zr -2.8 nm, Zr Si₂) *22.5, 160 mm with $T = 65\%$
- **Multilayer films are superior to monolayers and bulk materials in mechanical strength**
- **84% transmission with thickness of 20 nm – used as pellicle**
- Plasticization of thin films

Workshop Agenda

Tuesday, November 5, 2013

- **3:35 PM Session 5: Optics**
- **Characterization of Metrology Tools and Optical Components for HVM EUV Sources (S35) (Invited)**
- F. Scholze, *PTB, Germany*
- **0.7 to 30 nm EUV beamline at BESSY, 5-50 nm at PTB. Collectors up to 670 mm can be measured**
- Relative standard uncertainty of detector calibration : <1.2 to 0.3%
- Measurement of polarization for high NA optics
- **New EUV-Ellipso-Scatterometer**

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Tuesday, November 5, 2013

- **3:35 PM Session 5: Optics**
- **LPP Collector Mirrors – Coating, Metrology and Refurbishment (S34) (Invited)**
- **Torsten Feigl, *optiX fab, Germany* -spin-off from IOF**
- First Collector - 230 mm collector - π sr (2004)
- 300 mm Collector, $R > 66.5\%$
- High temperature coatings $R > 58\%$
- $R > 50\%$ with 660 mm dia
- **120 B pulse lifetime due to new cap layer**
- **Refurbishment – recovered 90% of the reflectance of the collector via replacement of some layers**
- **Complete recoating – reflectivity similar to that of a new collector**

Workshop Agenda

Wednesday, November 6, 2013

- **8:30 AM Announcements**

Coherent X-Rays from Tabletop Femtosecond Lasers and Applications in Nanometrology (S1)

- Margaret Murnane, *University of Colorado, Boulder*
- **Ability to take HHG into keV region and phase matching**
- **Harder challenge of “phase matching” in plasmas solved**
 - Static equation of phase matching
 - Counter intuitive – go to larger wavelength of lasers and higher harmonics >5000th order, high pressure
 - **keV HHG needs mid IR lasers (25 Micron). Limits are not known!**
 - 300- 1000 eV CE 1E-6to -7/eV, EUV power nW
- Applications in study of magnetic materials, acoustics metrology, **coherent diffractive X-ray imaging**, nanoscale heat flow
- **Sensitivity to pm displacements!**
- **Zepto and Yocto second physics!**

Workshop Agenda

Wednesday, November 6, 2013

- **9:20 AM Session 8: XUV – “Session Dedicated to the Memory of Prof. Alan Michette”**
- **Efficient Light Sources at BEUV & Water Window Soft X-ray Wavelengths (S41) (Invited)**
- Takeshi Higashiguchi, *Utsunomiya University*
- *13.5 high brightness* source with 10 micron laser and micro dot tin target. CE \sim 1%
- 4% CE from a Sn cavity target
- **Studied Z scaling with 10 ns to 150 ps pulses for drive lasers via EBIT and GEKKO II setups**
- **How to get low density – optically thin and high density plasma?**
- **Single shot flash source CE 0.1 %, 100 μ J for bio imaging – emission from Bi**
- Hybrid IR laser systems

Workshop Agenda

Wednesday, November 6, 2013

- **9:20 AM Session 8: XUV**
- **A Tunable Source of Quasi-Phase-Matched Coherent EUV Radiation (S23)**
- Kevin O'Keeffe, University of Oxford
- **Flexible Tunable pulse trains**
- Programmable pulse trains to compensate for varying L_c

Workshop Agenda

Wednesday, November 6, 2013

- **9:20 AM Session 8: XUV**
- **Complete Spatial Characterisation of EUV Harmonic Wavefronts (S22)**
- David Lloyd, *University of Oxford*
- Temporal and spatial characterization of light sources
- **Simultaneous measurement of coherence and wavefront.** SCIMITAR – from single scan
- Characterized HHG and can be applied to wide variety of sources

Workshop Agenda

Wednesday, November 6, 2013

- **9:20 AM Session 8: XUV**
- **Table-top EUV/Soft X-ray Source and Wavefront Measurements at Short Wavelengths (S18) (Invited)**
K. Mann, Laser-Laboratorium Göttingen
- LPP source for EUV and XUV (1- 10 nm and 10-20 nm)
- SO to study single pulse damage study
- **NEXAFS in the water window region – surface sensitive chemical analysis** via fingerprinting of molecules (excitation of unoccupied molecular orbitals)
- Spectro microscopy
- Hartman wavefront Sensor

Workshop Agenda

Wednesday, November 6, 2013

- **9:20 AM Session 8: XUV**
- **In Memory of Prof. Michette (S53)**
- Peter Anastasi (Silson)
- Review of many of his books on Soft X-ray and Laboratory Sources, his life as a researcher and professor

Workshop Agenda

Wednesday, November 6, 2013

- **10:55 AM Session 9: Metrology**
- **Droplet-based LPP Light Source for HVM Inspection Applications (S36)** Nadia Gambino, *ETHZ, Switzerland*
- **ALPS II facility overview (1.6 kW YAG laser, 20 K Hz, dispenser units)**
- **1300 W drive laser, 6 K Hz, 12 W source, >200 W/mm²sr, 70-95 micron source FWHM**
- Closed loop droplet tracking system and 3-D EUV distribution for droplet LPP
- Motorized array of Langmuir probes for LPP ion distribution
- Ga and In droplets for 6.x nm

Workshop Agenda

Wednesday, November 6, 2013

- **10:55 AM Session 9: Metrology**
- **Laser Produced Plasmas using Cryogenic Xe for Actinic Metrology and Inspection Tools (S20)**
- Mark Tillack, *University of California San Diego*
- **Upto 30 ns provide adequate CE for YAG and up to 120 ns for CO2 lasers (Sn)**
- EUV source size depends on laser intensity than on pulse duration
- **CE drops at most 10-15% with long pulses for Xe LPP**
- **Emitter size for Xe LPP increases with laser intensity**
- In-band plasma size at focus measurements
- Good agreement with modeling

Workshop Agenda

Wednesday, November 6, 2013

- **10:55 AM Session 9: Metrology**
- **Dynamics of a Laser-assisted Z-pinch EUV Source (S27)** I. Tobin, *Trinity College Dublin*
- Spectroscopic measurements of time evolution of plasma of Gallinstan and Sn
- **Temperature estimated - 2-6 eV, Ne estimate of 5.5 E18 cm⁻³**

Workshop Agenda

Wednesday, November 6, 2013

- **10:55 AM Session 9: Metrology**
- **Influence of an Intensive UV Pre-ionization on Laser Plasma with Xe Gas Target (S12)**
- *Serguei Kalmykov, A. F. Ioffe Institute, Russia*
- How to increase pre-ionization of Xe – difficult from Nd:Yag alone
- KrF lasers – plasma heating by this laser alone is 5- 70 weaker than one from Nd: YAG lasers
- **30-60% increase in EUV output when KrF pre-pulse was used. Increase in EUV signal upto 1 μ s time delays.**
- **Idea of a density wave in plasma with pre-pulse**

Workshop Agenda

Wednesday, November 6, 2013

- **10:55 AM Session 9: Metrology**
- **Development of Microwave Discharge Plasma for Extreme Ultraviolet Lithography (S10)**
- Saya TASHIMA, *Kansai University*
- 2.4 G Hz waveguide, 6 kW for generation of plasma
- Duration of EUV pulse is about 3 magnitude higher than from LPP system
- **1.25 W/2 pi sr, 100 Hz**
- **Plasma size – 2 mm dia for visible part of the plasma. Need to know plasma size in EUV and source brightness**
- Issues- heat load and need to make plasma smaller

Workshop Agenda

Wednesday, November 6, 2013

- **Tunable, High Brightness Lab-Scale Soft X-Ray Photons (S32)**
- P. Sheridan, *NewLambda Technologies*
- 0.25 m absolutely calibrated spectrometer for measurements
- **32 μ x 55 μ plasma size in EUV**
- Collector mirror has a 10 x magnification
- **13 nm /hour of debris at IF**
- **Brightness of 30 W/mm²sr**
- Application in Photoelectron spectroscopy and EUV IL
- Demonstrated stability of source

Thank you!

- Thanks for making 2013 International Workshop on EUV and Soft X-ray Sources a very productive workshop! Special thanks to:
 - Workshop Sponsors
 - EUVL Workshop Steering Committee
 - Session Chairs
 - Presenters
 - Padraig Dunne
 - **UCD Physics Office Staff (Stephanie, Barbara, Elaine, Lynka, John) and Robert, Paddy and Tom!**
- **Hope to see you again in 2014!**



2014 International Workshop on EUV Lithography

Maui, Hawaii

June 23-27, 2014

Upcoming Workshops



2014 International Workshop on EUV and Soft X-Ray Sources

Dublin, Ireland
November 3-6, 2014